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SPECIAL ISSUE

THE VALUES OF WETLANDS: LANDSCAPE AND INSTITUTIONAL PERSPECTIVES

Approaches to valuing the hidden hydrological services of wetland ecosystems ☆

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Abstract

This paper investigates the role of the production function approach in capturing the value of hydrological services of wetland ecosystems. Hydrological research in the Hadejia-Nguru wetlands in northern Nigeria suggests that the major role of the wet season inundation of the wetlands is in recharging the underlying aquifers. This paper shows that the hydrological services extend beyond direct use values, and have a significant economic value associated with them. Whereas the direct benefits provided by the wetlands, such as floodplain agriculture, fishing and forestry, have previously been assessed, this paper synthesizes the results of two approaches to capture the value of indirect benefits derived from the role of the wetlands in replenishing and maintaining groundwater resources within the wetland area.

Keywords: Valuation; Production function; Wetlands; Ground water recharge

1. Introduction

Wetland ecosystems are associated with a diverse and complex array of direct and indirect uses. Direct uses include the use of the wetland for water supply and harvesting of wetland products such as fish and plant resources, while indirect benefits are derived from environmental functions such as flood water retention, groundwater recharge/discharge, nutrient abatement, etc., depending on the type of wetland, soil and water characteristics and associated biotic influences (Mitsch and Gosselink, 1993). In particular, floodplain wetlands are associated with groundwater recharge or discharge, and individual floodplains may exhibit either or both of these functions (Thompson and Hollis, 1995).

This paper synthesizes the results of two case studies on the economic analysis of the groundwa-

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ter recharge function performed by the Hadejia-Jama'are wetlands. Two approaches to valuing an environmental function as an input in production are briefly discussed. A production function approach is applied to groundwater-fed agricultural production and a domestic water demand analysis is used to value groundwater recharge in domestic water use. Both studies use a static analysis to measure changes in welfare over a single dry season, with no technological change. Primary data collection on agricultural production and domestic water consumption was carried out over the dry season. Water use during this season, which lasts from November to April, is primarily from groundwater since there is little surface water available during this season.[1]

2. Valuing the environment as an input

The purpose of this paper is to emphasize the role of establishing the linkages between ecological and economic systems to facilitate the valuation of ecosystem services in developing countries. Because of incomplete markets, these values are unlikely to be captured by land or product prices, particularly in developing countries. The value of these services in supporting local economic production could, however, be substantial.

While the assignment of monetary values to economic goods and services is acceptable to most people, assigning monetary values to environmental resources, particularly in order to capture non-use values, invokes moral and ethical arguments that may never be resolved. Nonetheless, indirect uses of environmental systems require some form of value assignment, in terms of both establishing the physical/ecological linkages that make such uses possible, as well as in terms of partially measuring the derived economic benefits from these uses. Knowing this, and by incorporating the benefits and costs of environmental effects into an analysis of development alternatives, we are better positioned to decide which alternative would provide the largest net benefit to society.[2]

An ecological function, such as groundwater recharge or discharge, may have indirect use values for activities which may be far removed from the ecosystem and therefore difficult to identify; or the function itself may be poorly understood and benefits derived from it may not be easily attributable. Prior to attempting the valuation of these indirect benefits, two essential pieces of information must be, therefore, elicited. These are: (1) identification of the physical or environmental linkages which result in and maintain a particular ecosystem function or service; and (2) identification of the economic linkages which help realize the value of these hidden hydrological services. The indirect use value of an environmental function is related to the change in the value of production or consumption it supports. The identification of demand for a consumptive use and the costs of supplying it are necessary in order not to overestimate the benefits of an environmental improvement (Freeman, 1993; Bockstael et al., 1999).

The economic concept of value used in this paper has its foundations in neo-classical welfare economics. The economic value of changes in environmental resources and services is derived from measuring the effects of these changes in human welfare. In the case studies presented here, the services of the environmental resource are identified as an input in the production of some marketed or marketable good. The household production function approach was developed on the theory of consumer choice (Becker, 1965; Lancaster, 1966). The approach is based on the observation that households derive utility from goods produced through combining purchased goods with household labor or time. By explicitly

[1] For details on the survey instruments used for data collection, see Acharya (1998).

[2] Numerous methods are available to estimate values of ecosystem services and many have been applied to wetlands (e.g. Hammack and Brown (1974), Lynne et al., (1981), Farber and Costanza (1987), Bergstrom et al., (1990), Gren et al., (1994), Morrison et al., (1998), Bell (1997)). However, the vast majority of applications have been in industrialized countries and the valuation of recreational benefits has been an overriding topic of interest.

incorporating non-marketed environmental goods in the modeling of consumer preferences, valuation techniques based on the household production function can relate household expenditures on private goods to the derived demand for environmental goods. Recreational uses, for example, are modeled with time and environmental resources as inputs in the production of recreational activities (e.g. Bockstael and McConnell, 1983; Smith et al., 1983).

The household production function may be described by the following utility function: $U = U(\mathbf{Z}, f(x_i...x_j, W))$; where $\mathbf{Z}$ is a vector of purchased goods for final use and the production function, $f(x_i...x_j, W)$, describes the production of a good Q by the household using both private goods, $x_i...x_j$, and the environmental good W as inputs. Hence, the household consumes $\mathbf{Z}$ as a final good and also produces Q. The household is then expected to maximize this utility function subject to a budget constraint and the derived demand function for the environmental good can be estimated.

In the more general case of the household production function, the production function approach can capture the indirect use value of environmental goods in the production of some marketable goods. The environmental good is a *factor input* in the production process (Ellis and Fisher, 1987; Mäler, 1992; Freeman, 1993; Barbier, 1994). Mäler (1992) develops the use of the production function for measuring the value of an environmental resource when the output of the production function is measurable, such as crop production. If the output is measurable and the production function is described by $Q = f(x_i,...x_k, W)$, where Q is the measurable output, $x_i,...x_k$ are inputs of goods and services and W is the input of the unpriced environmental resource, then the economic value of a small change in the resource supply (holding all other prices constant) is the value of the production change that will accompany the change in the resource availability.[3]

[3] If the output Q cannot be measured directly, then either a marketed substitute may be used, if it exists, or possible complementary or substitutability between the resource and other inputs must be explicitly defined (see Mäler, 1992 for a complete discussion).

The welfare change measured by this method is the sum of the consumer and producer surplus measures. However, if the production units are small relative to the market for the final output, and they are essentially price-takers, it can be assumed that product and variable input prices will remain fixed after a change in the environmental resource, W. In this case the benefits of a change in W will accrue to the producers (Freeman, 1993).

While the production function approach provides a useful way in which to value environmental functions, the pervasive lack of adequate data on how an environmental function is linked to the production of other goods often means that the welfare analysis needs to make a number of assumptions. Although the case studies presented here rely on the hypothesis that agricultural production and domestic water consumption are affected by groundwater levels, we can in fact relate changes in groundwater levels to recharge rates based on hydrological relationships between flood extent, groundwater recharge rates and groundwater levels.[4] Furthermore, as the second of the valuation studies presented below show, data requirements for the use of the household production approach may also be met by combining stated preference and revealed preference data.

3. The Hadejia-Nguru wetlands: a case study

This section briefly describes the Hadejia-Nguru wetlands in Northern Nigeria and highlights the role of these wetlands in recharging the shallow aquifers within the region. It then applies the previously described methodology of valuing environmental functions as inputs in the production of a marketable good and calculates a value for this ecosystem function by hypothesizing changes in recharge rates due to changes in flooding extent.

[4] The hydrological model and data referred to in this paper were developed and collected by the Hadejia-Nguru Wetlands Project (HNWCP) and by University College London. See Thompson and Hollis (1995) and Thompson (1995) for further detail on the hydrological model, and Thompson and Goes (1997) for more information on the calculation of recharge rates and related changes in groundwater levels in the study area.

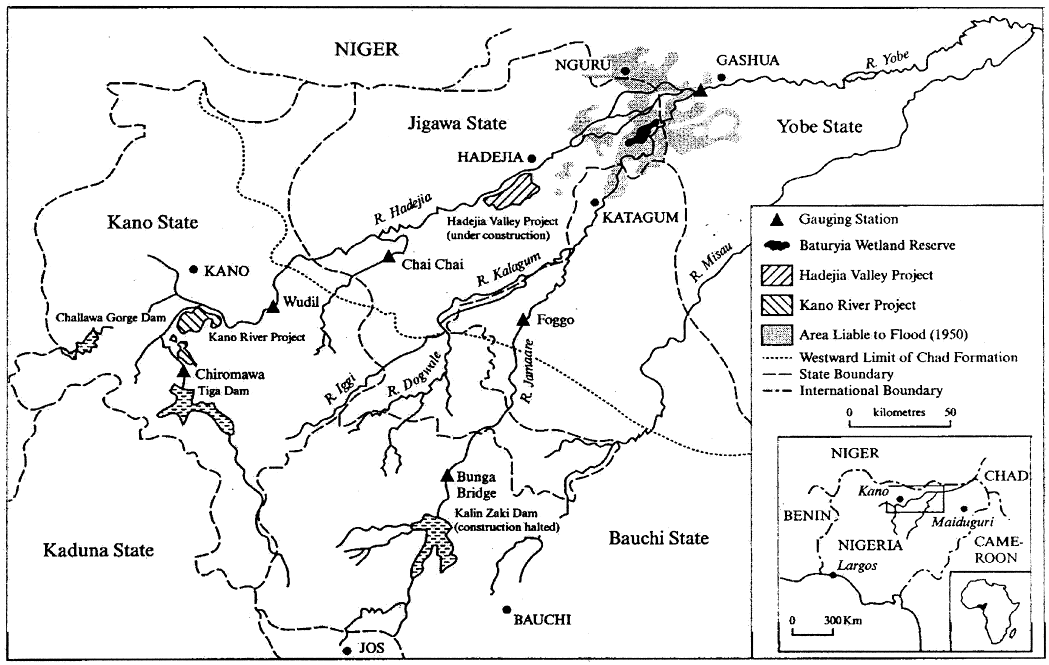

Fig. 1. The Hadejia-Nguru wetlands. Source: Hollis et al., 1993.

The Hadejia-Jama'are floodplain is formed by the waters of the Hadejia and Jama'are rivers which meet to form the Komaduga Yobe river, flowing northeast into Lake Chad (Fig. 1). This area receives about 600–700 mm of rainfall per year, over a 3–4 month rainy season, lasting from June to September. Almost 80% of the total run-off from the rivers takes place during the months of August and September and the rivers have periods of no flow in the dry season which lasts from October to April (Thompson and Hollis, 1995). The wetlands are formed by the regular flooding of the rivers during the rainy season when the water spreads amongst inactive sand dunes (Adams, 1993). Low lying flooded areas known as *fadamas* are thus formed and are valuable for grazing, agriculture and other domestic uses.

The wetlands are an important site for wildlife conservation and wildfowl and support a wide range of economic activities, including wet and dry season agriculture, fishing, fuelwood collection, livestock rearing and forestry (Adams and Hollis, 1988; Adams, 1993; Hollis et al., 1993; Thomas et al., 1993). Eaton and Sarch (1996) note the importance of wild food resources found within the wetlands and the extensive use of these resources by the wetland populations.

A number of irrigation schemes within the Hadejia-Jama'are basin have been constructed or are being constructed (Thompson and Hollis, 1995). The location of these schemes, all upstream of the wetlands, will result in reductions of water supply to the wetlands. The opportunity costs of upstream water diversion projects are substantial (Barbier and Thompson, 1998). The present value of the agricultural, fishing and fuelwood benefits provided by the wetlands was calculated as being between Naira 846 and 1276 per hectare.[5] These returns from floodplain agriculture, fishing and fuelwood collection compared favourably with the net economic benefits expected from the Kano River upstream irrigation project.

In recent years, the maximum flood extent has declined from between 250 000–300 000 ha in the 1960s and 1970s to around 70 000 to 100 000 ha more recently (Hollis et al., 1993). The drought

[5] Exchange rate (March 1996) Naira 88 = $1

years experienced in Sub-Saharan Africa over the last two decades have led to a marked decrease in the discharge of the region's rivers. The combined effect of the drought and construction of upstream projects has been to reduce flooding in the wetlands from 2350 km^2 in 1969 and 2004 km^2 in 1974 to 962 km^2 in 1991, 525 km^2 in 1992 and 413 km^2 in 1993 (Thompson and Hollis, 1995). Adams (1993) notes that this shrinkage of the wetlands has taken place over the same period of time as an intensification of demands for their use.

The wetlands have been noted as being particularly important for the recharge of the Lake Chad groundwater aquifer (see Schultz, 1976 and DIYAM, 1987, cited in Thompson and Hollis, 1995). It has further been observed that the depth to groundwater in general increases away from the river channels that supply water to the wetlands, indicating therefore the greater scarcity value of groundwater in areas further away from the *fadamas*. The majority of the 1.5 million people living within these wetlands are dependent on groundwater supplies for drinking water and domestic water use (Kimmage and Adams, 1992; Hollis et al., 1993; Acharya, 1998). Dry season irrigated agriculture is also increasing within the wetlands and uses the shallow aquifer resources for its water requirements. The valuation of this recharge function is therefore required in order to obtain a better assessment of the opportunity costs of floodwater reduction in the wetlands. The information obtained from this valuation study, in terms of water requirements within the wetlands and in areas beyond, will improve our understanding of the economic and social importance of the wetlands and could also help in identifying an optimal floodwater release system for the dams, based on both the hydrological and economic requirements of the area (Acharya, 1998).

3.1. Welfare change in agricultural production and domestic water consumption

Within the wetlands, the two main uses of groundwater are in domestic water consumption and dry season agricultural irrigation. The valuation methodologies developed are based on the household/production function approaches discussed above and are adapted to suit the type of hydrological and economic data available.

The first part of this section is based on Acharya and Barbier (2000) and estimates the value of groundwater used in *dry season agriculture*. The second part studies the use of groundwater in *domestic water consumption* and reports results from Acharya and Barbier (1998). Using a hypothetical change in recharge rates, the value of the recharge function in these sectors is estimated. Economic data were collected for both groundwater recharge studies during November–December, 1995 and March–April, 1996 by the author, and hydrological monitoring was carried in the study area by the Hadejia-Nguru Wetlands Conservation Project. Table 1 outlines the basic underlying production models used for the two studies.

Reduced flooding in the wetlands will result in lower recharge rates and reduced groundwater levels (Thompson and Goes, 1997). The flood extent in the wetlands in 1994–1995 was approximately 78.03 km^2 and in 1995–1996 the flood extent was recorded at 56.91 km^2. The resulting change in groundwater recharge manifested itself as a change in water table elevations which dropped from 2.50 in 1994–1995 to 1.47 m in 1995–1996, a distance of ≈ 1 m from 1994–95 to 1995–96. As a result of proposed projects upstream of the wetlands, reduced recharge is expected to result in lower groundwater tables, ranging from -0.82 to -4.28 m, depending on the extent of upstream impoundment of water (Thompson and Goes, 1997). To illustrate the impact of such a decline in recharge, the valuation approaches summarized here estimate welfare losses for a 1 m decline in groundwater levels.

3.2. Valuing the recharge function through agricultural production

Irrigation for dry season agriculture is possible through the use of shallow tubewells and, to a lesser extent, with deeper boreholes. The use of shallow tubewells is rapidly increasing within the wetlands. These tubewells tap into the shallow aquifer which is maintained by recharge from the wetlands. Using production and market data, the per hectare value for irrigated agriculture in the

Madachi area is estimated as 36 308 Naira or US$ 412.5 per hectare (Acharya, 1998). We are, however, interested in investigating the welfare impacts of reduced recharge on agricultural production based on the use of these shallow tubewells.

Using the production relationships outlined in Table 1, we solve explicitly for the effects on social welfare of a change in groundwater levels, R, due to a fall in recharge rates. We assume price taking behavior and that there exists an inverse demand curve for the crop output Q_i. The effect of a welfare change due to a change in groundwater levels is observed in the production function through an impact on water input, W_i. We assume that all other inputs are held constant and at their optimal levels, and that all input and output prices, with the exception of c_w, are unchanged. For a non-marginal change in groundwater levels from R_o (old level) to R_1 (new level), the welfare change measure associated with a change in naturally recharged groundwater is the resulting change in the value of production less the change in pumping costs. Denoting S_i as the social welfare arising from producing Q_i, we measure social welfare as the area under the demand curve for Q_i, (denoted by $P_i(u)$) less the cost of the inputs, including groundwater, used in production.[6]

$$S_i = S_i(x_{i1,}...x_{iJ}, W_i(R); c_w(R)) = \int_0^{Q_i} P_i(u)\,du - \boldsymbol{C}_x\boldsymbol{X}_J - c_w(R)W_i \quad \text{for all } i, j \tag{1}$$

A marginal change in pumping costs affects the total costs of water pumped. Hence the welfare effect of a change in water input due to a change in groundwater levels occurs both directly through the production function and indirectly through the marginal effect of a change in pumping costs on water input, $c_w(R)W_i$. An increase in groundwater levels (to a point) would result in a welfare benefit, or at least maintain the initial welfare levels, whereas a decrease in groundwater levels would result in a welfare loss, either due to increased pumping costs and/or to a change in productivity.[7] The farmers supply their products to a single market. Therefore, we assume that they face the same production and cost relationships

Table 1
Agricultural production and household production models used in the valuation studies

Agricultural production[a]	Domestic water consumption[b]
$Q_i = Q_i(x_{i1},...x_{iJ}, W_i(R))$ for all i	Max $U = U(Q,W)$
$C_i = \boldsymbol{C}_x\boldsymbol{X}_J + c_w(R)W_i$ for all i	s.t. $W = W_p + W_c$; $W_c, W_p \geq 0$
$P_i = P_i(Q_i)$	where $W_c = \dfrac{L_w}{\alpha}$; $Y(L_0 - L_w, z) \stackrel{\alpha}{-} P_w W_p = Q$
where:	where:
Q_i = the output of the ith crop	Q = good produced by the household (taken to be a numeraire good with price = 1)
W_i = water input for the ith crop	W = total water demanded by the household
$\boldsymbol{X}_J$ = vector of $x_1,...x_j$ = other variable inputs; $j = i,...J$	L_0 = total household labor
R = depth to the groundwater level	L_w = labor used in collecting water
P_I = market price of Q_i	P_w = price of vended water
C_I = cost of production for the ith crop	W_c = quantity of water collected by the household
$\boldsymbol{C}_x$ = vector of $c_{xi},...c_{xJ}$, strictly positive input prices	W_p = quantity of water purchased by the household
	Y = household income
c_w = unit pumping costs for water	Z = household characteristics
	α = time cost of collecting water

[a] Source, Acharya and Barbier (2000).
[b] Source, Acharya and Barbier (1998).

[6] The demand function is assumed to be compensated so that consumer welfare can be measured by the appropriate areas. The production units are small relative to the market for the final output, and the farmers are essentially pricetakers. It can therefore be assumed that product and variable input prices will remain fixed after a change in the environmental resource, W, and that the benefits of a change in W will accrue to the producers (Freeman, 1993).

[7] We expect dS/dR to be positive as long as the water table is not so high as to cause waterlogging and subsequently cause direct damage to crops and/or changes in soil conditions.

Table 2
Vegetable production function[a]

Variable	Log-linear
ln (labour)	0.231
	(0.823)
ln (labour)	0.585**
	(2.206)
ln (fertiliser)	0.593**
	(2.827)
ln (water)	0.4268**
	(2.437)
Constant	3.13***
	(11.439)
Adjusted R^2	0.66
F statistic	18.88
Breusch–Pagan χ^2	4.24 (d.f.4)
Observations	37

[a] Sample size = 37 observations; t-statistics in parenthesis.
*** 1% significance level.
** 5% significance level.

for each crop i and are price takers, and that it is possible to aggregate the welfare effects of a change in groundwater levels for the individual farmer, across all farmers in the wetlands.

In estimating production functions, we assume that the output of crops depends on a combination of purchased goods and water inputs. For example, for vegetable production the production function was estimated as a single function since all the vegetables are grown at the same time or in quick succession and receive similar quantities of inputs.[8] The general form of the production function is given by:

$$Y = f(L,B,F,W) \tag{2}$$

where

Y = total output of crop (kg)
L = land (ha)
B = labour (workers)
F = fertiliser (kg)
W = water application = irrigation (l)

We consider linear, log-linear and quadratic functional forms for vegetable production. The log linear form described below, where ε is the residual term, assumes constant input elasticity and variable marginal products, and provides the best fit to the data (Acharya and Barbier, 2000):

$$\ln Y = \alpha + \beta_1 \ln L + \beta_2 \ln B + \beta_3 \ln F + \beta_4 \ln W + \varepsilon \tag{3}$$

The total loss associated with the 1 m change in naturally recharged groundwater levels (resulting in a decline of groundwater levels to approximately 7 m) is estimated as 383 642 Naira or 4360 US$ for the study area (Tables 2 and 3). For the 134 farmers in the study area who grow only vegetables, the change in welfare associated with a decrease in recharge to the aquifer is estimated as 2863 Naira (US$ 32.5).

Shallow aquifers could potentially irrigate 19 000 ha within the wetlands through the use of small tubewells (DIYAM, 1987). Using this figure together with the average welfare change for the study area, the welfare loss associated with this change in groundwater levels amounts to 82 832 US$ for the wetlands, due to a decrease in groundwater levels to ≈ 7 m in depth, over a single season.[9]

3.3. Valuing the recharge function through domestic water demand analysis

In addition to groundwater irrigated agriculture, the main use of groundwater in the wetlands is for domestic water consumption. Wells are used to meet drinking water requirements throughout the year and this dependence increases during the dry season. Our analysis of domestic consumption of groundwater resources initially carries out a demand analysis of water consumption by rural households that rely on groundwater resources for their domestic needs. A household production function approach is used to model the demand for collected and/or purchased water (Table 1). The results of this analysis are then used to calcu-

[8] Data on seeds/seedlings were unreliable and this variable was not included in the production function.

[9] Note that this figure is based on 32% of installed tubewells actually working in the study area and could be much higher for a higher percentage of operational tubewells within the wetlands (Acharya, 1998).

Table 3
Welfare change for Madachi farmers (in Naira)[a]

Crop	Total welfare change (Naira)	Average welfare change per farmer	Average welfare change per hectare	Total land (hectares)	Average land holding (hectares)
Vegetables	105 916	2863	3566	29.7	0.803

[a] Exchange rate: 88 N = US$ 1.

late welfare changes due to hypothetical changes in groundwater levels, based on recharge rates determined by flood extent within the wetlands.

Observations of water demand are based on a dry season household survey carried out by the author during 1995–1996. Data on both observed prices and quantities, and collection times for each household within the sample, as well as other relevant socio-economic information were used in this analysis (Acharya, 1998). During the course of the study it was found that households were either: (a) collecting all the water demanded by their household; (b) purchasing all the water demanded by their household; or (c) collecting and purchasing water demanded by their household. The sampled households were separated into these categories. Distances from households to wells and back, and collection times, which include travel time to and from the well as well as time taken at the well, were recorded. All the villages are familiar with the vending of water and the price of water in the villages ranged between 2.00–5.00 Naira per 36 l. The contingent behavior data was collected by varying prices and collection times and recording household responses (Acharya, 1998).

The revealed preference and stated preference data were pooled. Given the relatively few observations for water consumption, by combining demand for water at different contingent ‘prices’ we are able to define a demand schedule for each individual in the data set. In the developing country context, particularly in rural areas where time series data is difficult to come by, this is a useful method to augment demand data.[10]

[10] Prior to analysis, however, it has to be determined (for example with the use of a Chow test) whether the two types of data represent the same underlying preference structure. This was confirmed for this analysis.

Aside from differences in water consumption levels, households in these three categories are also differentiated by employment and income levels. A higher percentage of households that only purchase water are involved in local trading in addition to farming and fishing activities. Since collected water and purchased water are perfect substitutes in consumption, the household has the choice of consuming either good or a combination of the two (but must consume at least one of these goods since water itself is an essential good). The household may be consuming both goods, but at a certain level of P_w or α the household is observed to change its allocation between the goods, and at some point may switch entirely to consuming a single good. The analysis assumes there are two markets for water, i.e., one market for water collected by households (with price α) and one market for water purchased from vendors (with price P_w). The household's choice of a water procurement method is determined by relative prices for collected water and vended water and household characteristics. Linear demand functions are estimated for households which collect and those which purchase and dummy variables are used to differentiate between corner and interior solutions.

Demand for collected water is given by:

$$W_c = c_1 + a_1\alpha + a_2D_c\alpha + a_3\alpha z + a_4D_c\alpha z + a_5z + a_6D_cz + a_7D_cP_w + \varepsilon_1 \quad (4)$$

and the demand for purchased water is given by:

$$W_p = c_2 + b_1P_w + b_2D_pP_w + b_3D_p\alpha + b_4D_p\alpha z + b_5z + b_6D_pZ + \varepsilon_2 \quad (5)$$

where:

Table 4
Demand for water[a]

Explanatory variables	Collected water	Purchased water
Price per l	–	−166.69***
		(5.478)
Price* household dummy	53.771°	–
	(1.283)	
Collection time	−0.286°	–
	(1.297)	
Collection time *household dummy	−3.187***	1.687*
	(4.737)	(1.741)
Ratio of children to adults *household dummy	−33.513***	22.982*
	(4.322)	(1.879)
Household size	6.586***	3.701***
	(8.452)	(4.221)
Household size *household dummy	−1.803°	−0.586
	(1.498)	(0.542)
Trade	32.815***	55.550***
	(2.415)	(3.943)
Civil service		
	2.846	28.158*
	(0.205)	(1.892)
Civil service *household dummy	6.728	−35.985°
	(0.583)	(1.337)
Other occupation	−28.778*	–
	(1.664)	
Trade *collection time	3.222***	
	(4.606)	
Trade *household dummy *collection time	−3.699***	0.917
	(3.942)	(0.889)
Ratio of children to adults *time *dummy household	1.543***	–
	(3.263)	
Constant	140.16***	48.396***
	(8.688)	(2.968)
Observations	836	836
Adjusted R^2	0.64	0.11

[a] Not all occupation variables are used in the varying parameters to overcome the problem of singular matrixes. Coefficients with significance levels < 20% for both demands are not reported; t-statistics in parenthesis.

*** 1% significance level.

* 10% significance level.

° 20% significance level.

W_c = demand for collected water (collected by the household for own consumption).
W_p = demand for purchased water.
α = collection time (for 36 litres of water per trip).
P_w = price charged by vendor per 36 litres of water.
z = exogenous factors affecting income generation including household characteristics such as household size, children/adult ratio, occupation.
αz = interaction between collection time and certain household characteristics.
D_c = dummy variable where; $D_c = 0$ if household is collect only and 1 if household both collects and purchases its water.
D_p = dummy variable where $D_p = 0$ if household is purchase only and 1 if household both collects and purchases its water.
$\varepsilon_{1,2}$ = random errors associated with each demand function.

Using a seemingly unrelated regression model applied to the panel created by pooling the stated and revealed preference data, Acharya and Barbier (1998) estimate demand across the two markets for collected and purchased water (Table 4). These are estimated by a two-step feasible generalised least square procedure (FGLS). In general the signs on the coefficients are as expected and the models behave well in terms of reduced heteroscedasticity from OLS estimates and account for the correlation across the two equations. Using these estimates of water demand functions for collected water and purchased water the welfare effects of a change in groundwater levels can be derived. Changes in groundwater levels are expected to affect collection time (α) and price of vended water (P_w), assuming all other household characteristics remain constant.

To value the change in the recharge function due to reduced flooding within the wetlands, we hypothesize a decrease of 1 m in level of water in the village wells, resulting in an increased collecting time of 25% and an increase in the price of vended water of ≈ 1 Naira. These changes in price are based on the evidence provided by the

Table 5
Consumer surplus changes per household (in Naira)

Households	Consumer surplus change	Average monthly income (Naira)	No. of representative households in wetlands	Welfare change for the wetlands (in Naira)
Purchase only	2.86	4779.38	22 650	64 779
Collect only	12.09	2660.55	57 013	689 287
Purchase and collect	19.93	7254.13	28 302	564 059
Average for all households	10.62	4898.02	107 965	1 146 588

survey data on the relationship between collection time and well water levels and on the change in price indicated by vendors as likely to occur in the event of a 1 m decrease in water levels.

Welfare changes are calculated as changes in consumer surplus, i.e. as the change in the area behind a household's ordinary demand curve between the relevant 'prices'. The estimated demand functions are Marshallian demand functions and the consumer surplus measure is an approximation of the welfare change measures associated with the Hicksian demand curve.[11] Change in consumer surplus is calculated for individual households, and average consumer surplus is calculated as the average of the sample. The average consumer surplus loss per household type is given in Table 5.[12]

4. Policy implications

Given an average consumption of 232 l per household (24 l per capita) the recharge function has a value of 0.046 Naira per l of water consumed by households per day. These results suggest that the value of the recharge function is 1 146 588 Naira or US$ 13 029 per day for the wetlands (Table 5). The average welfare change for a 1 m change in water levels is ≈ 10.62 Naira or US$ 0.12 per household. Based on the household-specific welfare figures given in Table 5, this amounts to a daily loss of $\approx 0.06\%$ for purchase only households, 0.45% for collect only households and $\approx 0.27\%$ of monthly income for purchase and collect households.

In terms of groundwater irrigated agricultural production, a value of at least 2863 Naira or US$ 32.5 per farmer per dry season is attributable to the present rate of groundwater recharge. This results in a per hectare loss of 3566 Naira or US$ 40.5. Based on an average household income of Naira 4898 per month, this welfare loss is $\approx 6\%$ of yearly income for vegetable farmers. It has been suggested that floodplain benefits will be affected by upstream developments such as dam construction and channelization which might reduce the flooding within the wetlands (Barbier and Thompson, 1998). The results presented in this paper on the value of the groundwater recharge function clearly establish a positive value of groundwater resources to the floodplain populations. These studies show that the recharge function performed by the regular flooding of the wetlands have benefits which should be included in an economic analysis of floodplain benefits. The failure of the wetlands to provide this daily level of recharge would result in a substantial economic loss for wetland populations deriving benefit from groundwater use for domestic consumption and irrigated dry season agriculture. These studies confirm that groundwater recharge is of considerable importance to wetland agriculture and domestic water consumption, and re-

[11] Consumer surplus will be a reasonable estimate of a multi-price change on welfare if the resulting income effects are small, as is evident in this example (Just et al., 1982).

[12] Since 33.7% of the total agricultural land is used for dry season farming; the agricultural wage rate is 80 Naira per day and the dry season lasts for 6 out of 12 months, the following weighting is used to calculate shadow prices for labor time spent in collecting water: $0.337 \times 80 \times 6/12$.

duced recharge resulting in lower levels of groundwater will result in a loss of welfare for the floodplain populations. The valuation of the recharge function contributes to existing information regarding the economic value of the Hadejia-Jama'are wetlands and is therefore of relevance to wetland and water use policies that could affect the present flow of environmental services from these wetlands. The approaches summarized in this paper further demonstrate the applicability of the production function and household production function approaches to the valuation of hydrological functions in developing countries.

These values are not, however, a measure of the total value of the environmental functions performed by the wetlands, and neither can they fully capture the value of the recharge function itself. In fact, the value of the groundwater recharge may be much higher than that reported by this study, given that without the presence of the groundwater resources many villages might have to relocate. This study only provides a partial estimate of the value of the recharge function and of groundwater resources to wetland populations. Furthermore, an important question regarding the sustainability of the present trend towards increased abstraction of groundwater remains. Competing uses of groundwater within the wetlands, such as that between irrigated agriculture and domestic water consumption, while relatively insignificant at the present time, could have potentially important implications regarding resource use and the imputed value of the recharge function.

The objective of this paper was to summarize the results of two related studies of ecological systems in a developing country and to present the possibility of applying the production function approach to valuing hydrological functions. The values generated by these studies only consider impacts on two sectors, omitting the impact of reduced groundwater recharge on pastoralists and on vegetation and wildlife within the area. As the studies reported in this paper suggest, such ecological functions are clearly important in maintaining the health of an ecosystem and its ability to sustain the species dependent on it. The economic value of ecological functions in sustaining the livelihood and cultures of human societies clearly cannot be disregarded in development and conservation policy.

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